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## Analysis of District Heating and Cooling systems in Spain

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### Abstract

Currently, district energy systems allow long-distance distribution of energy and the use of renewable energies, increasing their interest in the fight against global warming and the energy crisis. This paper presents the current deployment of heat and cold distribution networks in Spain in order to analyze their technical and economic potential, opportunities and future challenges. Subsequently, a comparison is made with the networks at an international level. It has been observed that heat and cold networks in Spain have increased substantially since 2013, but the installed power in 2019 of these systems to provide either heat or cold covers a very small proportion of the total demand. These systems in Spain are supplied mainly by biomass, natural gas or a combination of them, however, the use of renewable energy is still below the European average. It can be concluded that heating and cooling networks still do not have the potential to replace all the demand of the residential sector, although their implementation is important to achieve greater energy efficiency, more flexibility in supply, greater energy independence and to avoid the waste of energy resources. Thus, technical and financial barriers are identified.

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### 1. Introduction

The energy used in different countries to the public supply of the ambient heating, water heating, process heating, cooking, ambient cooling, process cooling or refrigeration is very representative in their Primary Energy Supply (PES) Systems. According to the International Energy Agency (IEA), heat is the largest energy end-use demand, accounting for the 50% of global final energy consumption in 2018 [1]. On the other hand, it is estimated that energy demand for cooling in buildings will overtake demand for heating by 2070 [2].

Despite renewable energies are increasing their contribution to powering heating/cooling systems, fossil fuels continue being the main drivers of the heating system, while most cooling systems are powered by electricity [1,3].

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In this context, additional new global risks and challenges associated with climate change and energy security have to be overcome; and minimizing leaks of efficiencies is turned an essential issue. Grouping thousands of individual heating/cooling installations in one or a few large central production facilities seems to be an efficient solution [4], looking for synergies between different energy sectors.

District Heating and Cooling (DHC) is, hence, an efficient energy solution that consists of a centralized heating and cooling supply system and a distribution network of insulated two-way pipes that connect energy sources to several clients [5], allowing the transport of steam, hot water and/or cold water [6]. DHC improves the energy efficiency, the quality of service and the reduction of CO<sub>2</sub> emissions [2–5,7–9].

DHC systems have been operating since the 14th century [10]. These installations, based mainly of steam transport are considered the first generation (1GDHC). In the second generation, steam was replaced by hot water (2GDHC), which allowed for fuel savings, but these systems were unable to control demand [11]. In the 1970s, the third generation (3GDCH) was developed, where pressurized water is still the heat transfer fluid, but temperatures are usually below 100 °C [4]. Currently, the fourth generation (4GDCH) is deployed, and it works with distribution temperatures below 50~60 °C, increasing competitiveness and flexibility [12]. Lund et al. [7] highlight the role of the 4GDHC in the integration of Renewable Energy Sources (RES). Nevertheless, it is starting to arise the early steps for the development of the 5th Generation District Heating and Cooling (5GDHC) [13]. An overall idea of this new 5GDHC is to use supply water to decentralized Water-Source Heat Pumps (WSHP) at a temperature in the range between –5 °C to 35 °C and being capable of working in heating or cooling mode independently of network temperature [13]. The combination of bi-directional and decentralized energy flows capacity brings new opportunities with respect to 4GDHC [13].

Considering the mentioned advantages of district systems in synchrony with low-carbon regulations and efficient energy transition in which Europe is getting involved [14], district heating and cooling networks are an opportunity to meet these objectives. Additionally, the overall digital transition allows the development of intelligent control to maximize the efficient use of energy sources and to have a better network flexibility [15], reducing the main cost in heat distribution [16].

This study aims to provide an overview of district energy systems, to analyze the deployment of the district energy system in Spain from 2011 to 2019 and to evaluate its technical and economic potential to identify opportunities and challenges. Results of this study can be extended with ease to other Mediterranean countries, such as Italy or Greece.

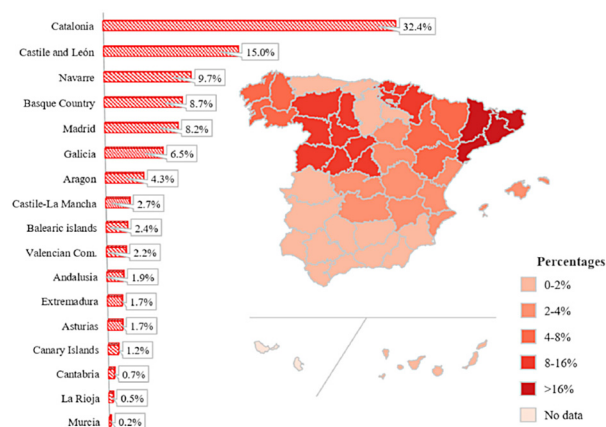
The remainder of the paper is organized as follows. Section 2 describes the materials and methods used in the study. Section 3 presents the results of the findings. Section 4 discusses the findings and, finally, Section 5 summarizes the main conclusions.

## 2. Material and methods

Data for the analysis of the evolution of DHC networks in Spain were obtained from a census carried out by the Association of Heat and Cold Network Companies (ADHAC) [17]. The results of the potential of heating and cooling networks were obtained from data from a report by the Spanish Ministry of Industry, Energy and Tourism [18]. The main parameter used to analyze the technical potential of an urban network was the energy demand which, according to the Directive 2012/27/EU, must be higher than 130 kWh/m<sup>2</sup> in order to be feasible. This consumption ratio is typically obtained in areas with high building density. Through census data and the review of the existing scientific literature, it will be possible to determine which are the future challenges faced by Spain in the implementation of these networks.

## 3. Results

This section presents the results obtained from the studies carried out in Spain on DHC systems with the aim of providing an overview of the current situation and the evolution of their deployment from 2013 to 2019. Subsequently, recent data on heat and cold consumption and its energy mix are shown. Finally, it presents the estimated technical and economic potential data of the different feasible energy resources that could be used in the future for heating and cooling networks in the residential sector.

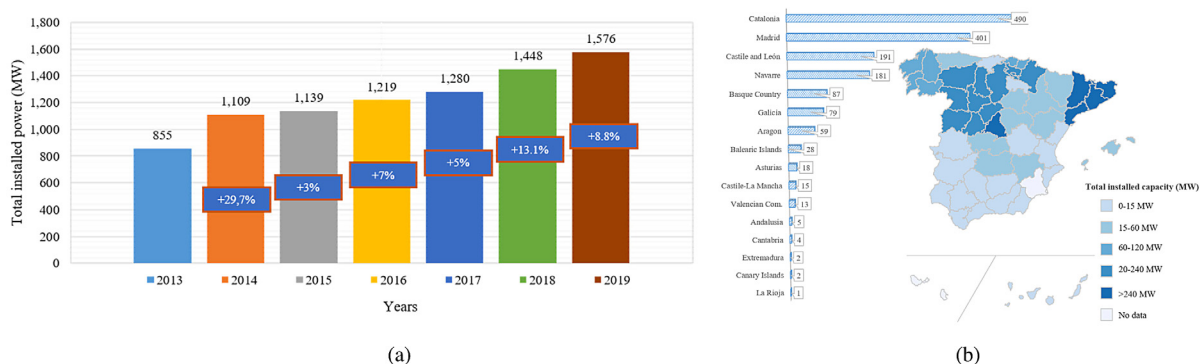


**Fig. 1.** Percentage distribution of DHC networks installed in Spain in 2019 by regions.  
Source: [17].

### 3.1. Situation of DHC systems in Spain

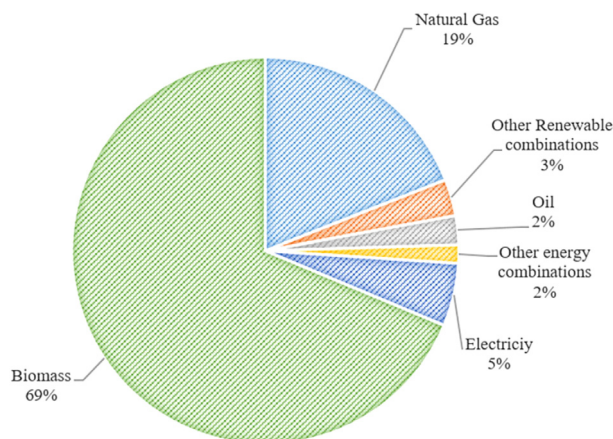
The number of networks censured in Spain since 2013 increased by an average of 20.5%, reaching 414 networks in 2019, with an estimated length of more than 740 km of pipelines [17]. Fig. 1 shows the percentage distribution of the networks located in the different autonomous communities. Cataluña and Castilla y León are the regions with the highest number of working installations nowadays.

In 2019, 426 networks have been identified, of which 414 were censured. The majority of the networks (374) are designed to provide heat, 36 networks can provide both cold and heat, and just 4 networks are designed exclusively for cold. From 2013 onwards, the power supplied increased substantially, by 66% until 2019, when the installed power was 1576 MW, as it can be seen in Fig. 2a. The regions that have bet more on DHC installed capacity are Cataluña, Madrid and Castilla y León, with an installed power higher than the others, as it is shown in Fig. 2b. The sector with the highest supplied power is the tertiary sector, with the 69% of the consumption, followed by the residential sector, with 23%, and the industrial sector with 8% [17].



**Fig. 2.** (a) Evolution of total installed power. (b) Installed capacity by regions.  
Source: [17].

Fig. 3 shows the 2019 energy mix in Spain, where most of the networks were supplied mainly by biomass and natural gas. Natural gas provides 19% of total installed capacity, while biomass provides 69%. Other minority energy sources used by the networks are: electricity, diesel, geothermal, cogeneration, waste heat, LPG, biogas and solar thermal. 80% of the networks were supplied exclusively from renewable energy sources, while the remaining 20% are energy combinations among which natural gas stands out [18]. It is estimated that the networks installed in 2019 saved 303 493 tons of CO<sub>2</sub> emissions.



**Fig. 3.** Power sources for DHC systems in 2019.  
Source: [17].

### 3.2. Heat and cold consumption in Spain

According to the Spanish Institute for Energy Diversification and Savings (IDAE) the consumption of renewable energy for heating was 37% of the total energy consumed in 2017 [19]. It is a much higher percentage of renewable energy than the percentage of installed power in urban networks.

### 3.3. Technical and economic potential of DHC systems in Spain

From the 3565 systems located with a total of 135.7 TWh of heat and 24.6 TWh of cold, the majority are placed in the residential sector. It is evaluated the energy demand for heat and cold, respectively, of the following different energy resources available in Spain: residual heat, thermal power stations, waste, geothermal, solar energy, biogas, biomass and cogeneration. The waste heat of industrial origin has a low potential for use in centralized systems, such as urban heat and cooling networks. This fact can be explained because the distances between thermal power plants and consumption centers are too large and the heat provided is reduced in relation to the necessary investment [18].

## 4. Discussion

As a consequence of efficiency gains due to the reduction in transmission temperature and the emergence of more efficient insulating materials, increased competitiveness, flexibility and digitization, heating and cooling networks have increased especially in the last decade [9]. Spain is a country with a low production in relation to the population in comparison with the other countries of the European Union, where they achieve more than 50%, such as in Latvia, Denmark, Estonia, Lithuania, Poland, Sweden or Finland [20]. None of the European Mediterranean countries overpass the 10 % [20]. Despite this, the number of networks in Spain increased by an average of 24% since 2013.

The distribution of power in district heating facilities in Spain according to the economy sectors differs from that of other EU countries, with the residential sector being the sector with the highest power supplied, followed by the industrial sector and the tertiary sector [9]. However, it is the tertiary sector that has the most power supplied in Spain.

Data from energy sources in Europe show that fossil fuels are the main source for these installations, with a proportion of 70%, being the remaining 30% fed by renewable sources. In Spain, in comparison with Europe, the use of renewable energy is a 10% lower. There is still a long way to go to reach the 20% of the renewable energy mix set by Directive 2009/28/EC.

The installed power in 2019 for heating and cooling, 1182 MWh and 394 MWh respectively, is equivalent to a very small proportion of the total consumption of heat and cooling in the residential sector in Spain in 2017, the

last recorded year. This means that urban networks in Spain still have much scope to replace the consumption of local heating systems.

The use of heat from thermal power plants has a limitation: the distance from the power plants to the end-use clients. The limitation of heat and cold networks in terms of distances was described above, with the maximum distance being 70 km. The technical potential for heating is to cover 9% of the demand for total heating consumption. However, if we consider only the economic potential, it would correspond to 6.5% of total demand. The technical potential for refrigeration could replace 6% and the economic potential is just 3.7% of total demand. Therefore, heating and cooling networks do not have sufficient potential to replace all the demand in the residential sector, but their implementation is important as it achieves greater energy efficiency, greater flexibility in supply, greater energy independence and does not waste energy resources, such as waste heat from industry, waste or heat from cogeneration plants.

In recent years, urban networks have reduced CO<sub>2</sub> emissions, thanks to the efficiency and use of renewable energy. By increasing the number of networks and the use of renewable energies can help to meet the European Union's targets [16].

The DHC technology developed in the last decades has allowed to increase the possibilities of implantation of the networks, due to the competitiveness, efficiency, security, flexibility in the use of energy sources, reduction of emissions responsible for global warming, reduction of costs and the improvement in transmission over long distances. However, in Europe there has not been a major deployment of networks yet, despite these improvements since the beginning of the last century.

It is necessary for institutions to promote these technologies by informing about their economic and environmental benefits, in order to increase their attractiveness for new investors. The promotion of public networks could lead to considerable savings in maintenance and fuel costs, as well as a reduction in emissions in the case of buildings with a large demand for heat or cold.

On the other hand, private networks can be profitable if they are installed in dense populations and multi-family buildings, with intelligent heat meters, IoT and Big Data analysis. These technologies could allow a real-time energy efficiency monitoring and conduct to an optimal energy use by improved control, increasing competitiveness.

An important challenge will be to correct the lack of statistics on heat demand in Spain. An increase in information in this field will help the design and construction of new projects, in short, it will be beneficial not only for researchers, but also to determine the feasibility of future projects.

Technically, one of the biggest challenges will be to improve the efficiency of the substation heat exchangers. This will allow to reduce the losses in the exchanger and, as a consequence, the necessary power supply will be reduced, which entails a reduction of the operation costs and therefore, an improvement of the competitiveness of the supplier and potential savings of energy and emissions. Although the pipelines materials have improved substantially, heat losses must be reduced. Transmission temperatures are now lower than they were a few decades ago, and in the future further improvements can be made in this area to increase transmission distances, which will allow viable projects to be considered that were not previously viable due to transmission losses.

Currently in Spain there is little information on the final price applied to the consumer. In the future it will be essential to have a reliable source to report the prices of DHC in Spain. This will avoid consumer misinformation when choosing which system of heat and cold suits them.

The management of energy resources will be important to meet peaks in demand. The use of storage systems will absorb such peaks in demand, providing greater security of supply. For tank thermal storage to be competitive, it will be necessary to improve its low energy density, reduce losses and control loading and unloading times. There are other storage alternatives, such as latent energy storage, which offers a high energy density but some problems still must be addressed, such as its low conductivity and corrosion damage [18]. Geothermal storage is also an alternative, but currently has high heat losses and poor control. Any improvement in thermal storage will help renewable energies, such as wind or solar, to be stored in the form of heat for use in the base and peak demands.

## 5. Conclusions

The observed results indicate that the DHC networks in Spain have been promoted substantially since 2013, increasing the installed power few regions, headed by Cataluña, Madrid, Castilla y León and Navarra. Spanish facilities are supplied mainly by biomass, natural gas or a combination of them, however, the use of renewable energy in Spain is still below the European average. The power installed in 2019 for heat and cold is still a very



small proportion of the total heat and cold demands. The analysis of the technical and economic potential that the energy resources for heating are: cogeneration, solar energy and biomass. In contrast, the use of heat from thermal power plants is limited by the long distances from the thermal power plants to the end-users. Heating and cooling networks do not have the potential to replace the entire demand of the residential sector, but their implementation is important to achieve greater energy efficiency, flexibility in supply, greater energy independence and avoid the waste of energy resources such as waste heat from industry or from cogeneration plants.

Finally, there are numerous opportunities aimed at achieving sustainable urban networks. The next challenges are aimed at replacing current energy resources with more environmentally friendly resources, improving thermal storage technologies, the use of intelligent metering equipment, techniques for processing large volumes of data, improving the efficiency of transmission equipment and substations, making up for the lack of heat statistics and the lack of information on prices.

### Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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